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VEDR.: PCT PATENTSØKNAD NR. PCT/NO3/00246 - OSMOTEX AS

Osmotex' application PCT/NO3/00246 describes a microactuator for pumping or mixing liquids, for which electroosmosis of the second kind (EO2) will be the transport mechanism. While several different means of electrokinetic / electroosmotic microactuators have been patented, they all suffer from the drawback of either needing very high voltages (typically kV range) or giving very low liquid velocity. It is important to overcome such drawbacks in order to make a commercial breakthrough for microfluidic devices (c.f. description in application).

Osmotex' invention has the unique feature that very high liquid velocities can be obtained (several mm / sec) at low electric potential drops (typically 25 V). The velocity is proportional to the square of the electric field strength ($v \sim E^2$). These features can be obtained only for the very special system described in the patent claims. Specifically, uni – directional liquid flow originates on the surface of highly conductive particles under the influence of an electric field that is neither too low nor too high, the limits being a function of the system geometry, electrolyte concentration etc (the correct electric field strength is specified in the patent claims). Typically, the minimum voltage drop is 20 – 80V. A uni – directional flow means that directed pumping is obtained by using symmetrical particles, using the special AC or DC electric fields specified in the patent claims.

This situation is very different from "induced charge electroosmosis" (ICEO), which results from the weak polarization of both sides of conductive or non – conductive particles. This mechanism prevails only at very low voltage drops, typically below 1.2V, above which water -- dissociation will start. As the velocity has a similar dependence on electric field strengths as for EO2, it will typically be slower by a factor of 600 or more (obtained by comparing the square of 1V and 25V, respectively). In addition, as the mechanism is inherently bi – directional (on a particle surface), net flow can only be obtained on the surface of asymmetric particles. Inevitably resulting in eddie flows, only a very small net flow can be obtained.

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On the background of the above, we do not consider the citation US20030164296A1 as being an X-citation. Further, only novelty, and no inventiveness, should be present towards the citation. The present application is obviously novel in respect to US20030164296A1.

Thus, we keep the claims unchanged, and despite the X-citation, we will together with the request for PCT phase II request substantive examination.

Further, we enclose substitute sheets no. 10-15, 17, 20, 24, 32, and 33. The amendments made are merely of editorial nature, and constitute no expansion of the application. The changes are marked on the first set of sheets 10-15, 17, 20, 24, 32, and 33. The second set of sheets 10-15, 17, 20, 24, 32, and 33 are the corrected sheets.

With kind regards,

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indirect actuation, e.g. setting the membrane of a peristaltic pump in motion by directly actuating a chosen liquid in contact with one side of the membrane, while the other side is in contact with the fluid of primary interest.

Smooth surface: By this should be understood that surface irregularities should be less than 5% of d_{char}, preferably less than 1% of d_{char}.

Characteristic diameter d_{char}: The dimension of the conducting means measured in parallel to the direction of the externally imposed electric field. When a number of conducting particles are contacting each other in the direction of the electric field, d_{char} is taken to be the whole length of the resulting conducting structure, measured in the same said direction.

Characteristic radii a_{char}: 0.5 times d_{char}.

Substrate: The material into which the microchannel or system of channels is produced, including e.g. the silicon wafer into which channels are etched, as well as top – plate constituting the channel roof.

The micropump according to the present invention is designed to transport liquid in the area of a few nanoliter ~~nonoliter~~ per min. to up to 50 ml per min. The amount of liquid depends on the specific applications, and is typically from several nanoliters (nl) / min for drug delivery, microliters (μl) / min for lab – on – a – chip applications , and several milliliters (ml) / min for cooling applications. For simplicity, the terms micropumps and microchannels will be used throughout the text, even if the prefix "nano" could be used for the lower part of the size range.

Figure 1 is a general outline of a microfluidic system 10 according to the invention. Preferable, the microfluidic network is arranged on or in a substrate 12. The figure shows two microchannels 20. The arrows indicate the fluid flow direction. The segment 20a is indicated as a portion of the microchannel 20. The electrical connection means (16)

establishes an electrical field E in the segment 20a and the conducting means 18 ensures that the liquid is forced in a given direction. Contacts for the electrodes 16 and sensor 22 are indicated with the reference numerical 24. It should be mentioned that the electrodes 16 could be placed anywhere in the microfluidic system, and also outside the systems, e.g. at the channel inlet and outlet. However, the designs with larger distance between electrodes are less prefered. Also, the actuator could be produced e.g. in a capillary instead of being microfabricated onto some substrate.

Figure 2 shows a top view of an embodiment of the present invention, with circular or spherical conducting means 18, which is fixed to the bottom and top of the channel section 20a. Here, the channel cross – section is rectangular. The distance between particles and between particles and the wall is approximately equal to a_{char}, thus both mixing and directed transport will take place. Also indicated on the figure are the walls of the channel 20, and position of electrodes 16 (dotted line). The flow direction is indicated by arrows.

In figure 3 is shown an embodiment of the invention with conducting means 18 shaped as two inclined (sloping) planes which are fixed to the channel walls and filling the depth of the channel (with rectangular cross section). Also shown on the figure are walls of the channel 20, position of electrodes 16 and flow direction (indicated by straight arrows). The distance between the conducting means 20 is varying from approx 2 – 0.5 a_{char}, thus some mixing will be obtained in addition to directed transport.

Figure 4 shows an embodiment similar to that shown in figure 3, but with conducting means 20 shaped as semicircular cylinders or semispheres. The distance between the conducting means 18 is approximately one characteristic diameter $\underline{2}$ ~~5~~ a_{char}, leading to both mixing and directed transport. The positions of electrodes 16 are indicated by dotted lines.

Figure 5 shows a microactuator with two connected layers of conducting means 18 shaped as circular cylinders or spheres in the flow direction. The conducting means are

fixed to the bottom and top of the microchannel 20. The position of electrodes 16 is indicated (dotted line), as well as the direction of flow. As the distance between the conducting means 18 and channel wall is approximately ~~approcimately~~ equaling a_{char}, both mixing and pumping will be obtained.

Figure 6 shows a sideview of a microchannel 20 including actuator segment 20a, substrate 12 (e.g. silicon, glass or polymer) and electrodes 16. Also shown is the channel top – plate (chosen among the same materials as the substrate), and flow direction. The segment of conducting means is indicated by dotted lines, but the conducting means 18 is not shown.

Figure 7 shows a top – view of the same structure as shown in figure 6.

Figure 8 shows an embodiment of the invention with substrate 12, and ellipsoidal or elliptical cylindrical conducting means 18, which is fixed to the channel bottom and top. Possible positions for electrodes 16 are indicated by dotted lines. As the distance between conducting means 18 is small, mostly directed pumping will be obtained.

The actuator in figure 9 is similar to the one depicted in figure 8, but has two layers of conducting means 18 in the flow direction, which are not in contact with each other.

Figure 10 shows a microactuator with two inclined (sloping) conducting means 18, which is fixed to the channel walls and filling the whole channel dept. The distance between the conducting means 18 is relatively small compared to a_{char}, thus directed transport will be obtained. Possible electrode positions are indicated by dotted lines.

Figure 11 shows another embodiment with sloping conducting means 18 similar to that shown in figure 10, but with additional layers of conducting means in the channel width.

Figure 12 shows a microchannel 20 with a widened channel segment including the channel segment 20a (limited by two dotted lines) containing the conducting means 18.

The latter is not shown on the figure. This actuator has the advantage of building up larger pressures.

In figure 13 is shown part of the channel 20 including microactuator section 20a, where the conducting means 18 is part of the channel walls. Circular shaped electrodes 16 is also shown. As the distance between the conducting means is small compared to a_{char}, significant directed transport will be obtained. Because of the higher conductivities of the conducting wall sections 18 compared to the liquid, the local electric field deviates towards said conducting means 18, creating both normal and tangential field components.

In figure 14 the geometry of part of the microchannel section 20 including microactuator section 20a and with sloping conducting means 18 is displayed. The angle between channel wall and surface of conducting means — λ is indicated, as well as original channel diameter d_0, normal distance between original channel wall and a point on the inclined plane h, characteristic diameter d_{char}, and channel length axis x.

Figure 15 shows the microchannel section 20a with conducting means in an embodiment with sloping conducting means 18 of circular geometry concentric to the rest of the microchannel 20.

In figure 16 is shown a microchannel with four electrodes. Here, the conducting means 18 constitutes part of the (cylindrical) channel, while the electrodes 16 placed up and downstream to this section (not shown). The conducting means could be a tubular ion – exchange membrane. A second pair of electrodes 16b induces the electric field normal to the flow, responsible for the SCR build – up. One of these are shaped as a circular tube concentric to the microchannel 20, and with a larger radii. It could consist of metal foil or -deposit, some conducting coating or surface treatment or other. The other electrode inducing the normal field could be a metal wire, which should be kept at some distance from the conducting means 18 by means of pieces of isolation or other fixing method. Preferably, it should be placed along the channel center axis.

Figure 17 shows a top view of the microchannel section 20a containing the conducting means in which one conducting particle is placed in a widening of the channel 20, keeping the area in a distance up to approximately $2a_{char}$, open for flow, resulting in efficient mixing. The next part of the microchannel section 20a mainly gives directed pumping, as the distance between conducting means and wall is below 0.5 a_{char}.

In figure 18 is displayed a channel cross section in an experimental setup, where conducting means 18 are fixed between two plates with microfabricated semicircular holes. The microchannel length direction is directed normally to the paper plane, and the channel side – walls are produced by sealing the plates by a sealing mass on each side. Spherical sulphonated styrene – divinylbenzene ion – exchange particles ~~was~~ were used as conducting means 18.

Figure 19 shows a top view of a microfabricated hole plate used for the experimental setup in figure 18.

Figure 20 shows a top view of the experimental setup, including conducting means 19, electrodes 16 and two liquid reservoirs on each side of the microchannel 20.

Generally, the conducting means 18 could have shape of ellipsoids, circular or elliptical cylinders, of spheres, semispheres, or any shape with a circular cross section. Further, it could have the shape of planes having an angle between 0 – 85 degrees with the applied electric field, preferably with an angle within 30 – 60 degrees. The conducting means should have a conductivity of at least 5 times that of the liquid to be actuated, preferably at least 10 times this conductivity.

The characteristic dimension of the conducting means (18) d_{char} should be within 0.1 μm and 5mm, but for most applications between 10 μm and 500 μm.

For applications ~~were~~ where predominantly directed EO2 pumping is desired, the space between the conducting particles 18, and between the conducting particles 18 and the

channel walls 20a, should be between 1/8 and ½ a_{char}. The distance to the wall does not apply where the conducting means 18 is attached to the walls, as in figure 3, 4 and 10, 11. For one layer of particles in the flow direction, this distance could be smaller or zero. If there is more than one layer, there must be space between the particles in each layer, or between the particles in adjacent layers, or both.

If mixing should also be obtained, the distances could be up to 2 a_{char}. For the largest distances, mixing is predominantly obtained.

Figure 13 shows an embodiment where the conducting means 18 is part of the microchannel wall 20. This is a special aspect of the invention and the EO2 condition is established by a declining in the local electrical field near the conducting means 18.

The length of the conducting areas should be the same as for conducting particles. The channel geometry could be rectangular, circular or elliptical. Here, d_{char} is the length of the conducting field, measuring in the flow direction. By analogy to the conducting particles, the distance between two opposite conducting walls should preferably be 1/8 – ½ a_{char} for obtaining directed flow. The conducting area could cover part of the channel circumference (e.g. the walls), or the entire channel circumference.

For the structure with conducting walls depicted in figure 13, the electrodes 16 could preferably be placed at some distance from the portion 20b of the channel walls, and occupying 1/3 of the channel width or less. They could be placed closer to the electrodes 16 than described above, and they could even be placed within the area 20b of conducting walls. Also, this structure could be extended by using several rectangular blocks of conducting means in the width of the channel. In such a geometry, the ends of conducting blocks could be electrically isolated, in order to increase the tangential electric field component.

For the structures containing one pair of electrodes 16, the electrodes should be placed up- and downstream in relation to the conducting area, respectively. These could be

The underlying concept of the invention is that the tangential electric field component works on the SCR induced by the normal component. The solvated ions in the SCR are then transported similarly to the ions in the EDL for classical EO. In both cases, the bulk pore liquid is set in motion due to viscous forces.

The EO1 velocity is given by the Smoluchowsky equation,

Equation 1

$$v^{EO1} = \frac{\varepsilon \zeta E_{\parallel}}{\eta}$$

Here, — ε is the liquid permittivity, — ζ the surface (zeta) potential of the wall, $E_{\parallel}$ the electric field strength parallel to the charged surface, and — η the liquid viscosity. For EO2, the velocity is given by the formula

Equation 2

$$v^{EO2} = \frac{2\varepsilon a_{char} E_{\parallel} E_{\perp}}{\eta}$$

$E_{\perp}$ being the normal electric field component.

In the case of other shapes of the conducting particle, d_{char} is taken to be the dimension measured in the flow direction. The SCR charge is approximately equal to d_{char} times E.

Classical electroosmosis (EO1) is caused by transport of permanent charges (ions) in the EDL. These ions are hydrolyzed (i.e. a number of water molecules are associated to each ion) or in general solvated (other solvent than water may be used). When the electric field sets the charges in motion, water is also transported. While this effect is taking place in a

2. A (normal) potential drop which is large enough for inducing the SCR. This means that the dimensionless potential drop across one characteristic particle diameter is larger than unity, which translates into:

Equation 3

$$E > 0.013V / a_{char}$$

3. The tangential field component must not be too large, otherwise the SCR are depleted of ions, and the SCR becomes thinner. Thus, the electric potential should not exceede:

Equation 4

$$E_{max\_SCR\_flux} = \left(\frac{3}{2}\right)^{\frac{4}{5}} \frac{RT}{F} m^{-\frac{2}{5}} \kappa^{\frac{4}{5}} a_{char}^{-\frac{1}{5}}$$

Here, R is the gas constant, T the temperature, F Faraday's constant, m a dimensionless constant equaling 0.2 for aqueous solutions, —and $\underline{\kappa}$ the inverse Debye – length.

4. The conducting media could be conducting by means of ions, electrons or holes; and it could be a conductor or semi – conductor. It should preferably be non – porous, but could also be porous, although this would lead to a reduced velocity. The best results are obtained for a permselective ion – conductor.

5. In order to avoid water splitting the concentration in the SCR should exceed the ion – product of water. As EO2 convection is counteracting the lowering of concentration resulting from polarization, a lower electric field strength above which no water splitting is present is observed:

automatically or manually changed and controlled during operation. This could be done based on information of the system performance obtained from the system microsensors.

Preferably, the signal frequency should be chosen to be higher than the inverse electrode polarization time,

Equation 7

$$t_{pol...} = \frac{L}{\kappa D}$$

where L is the distance between electrodes, — $\underline{\kappa}$ is the inverse Debye length (inverse EDL thickness), and D the diffusion coefficient of current carrying ions.

If an alternating or pulse electric signal should be applied, the maximum frequency is determined by the hydrodynamic time constant,

Equation 8

$$t_{HD} = \frac{a_{char}^{2}}{\nu}$$

where — $\underline{\nu}$ is the kinematic viscosity of the liquid.

PRODUCTION, MATERIALS, EXAMPLE SYSTEMS

Microfluidic devices can be produced by means of micromachining and processing techniques used in the microelectronics industry. This also applies to the micropumps according to the present invention. These methods allows one to make channels as well as

CLAIMS

1. Actuator (14) for use in a microfluidic system (10), wherein said microfluidic system (10) comprises a fluid network optionally in a substrate (12) consisting of at least one microchannel (20) arranged for transporting fluids; and an electrical connection means (16) for application of an electric field (E) across a segment (20a) of said microchannel (20) such that electroosmotic flow is induced in said segment (20a), characterized in that said segment (20a) comprises conducting means (18), wherein a surface portion of said conducting means (18) is curved, or inclined with respect to the electrical field (E).

2. Actuator (14) in accordance with claim 1, wherein the conducting means (18) has the shape of ellipsoids, spheres, cylinders, elliptical cylinders or cones.

3. Actuator (14) in accordance with claim 1, wherein the conducting means (18) consist of small cylinders with the longitudinal axis normal with respect to the fluid flow direction.

4. Actuator (14) in accordance with claim 1, wherein the conducting means (18) has the shape of particles with planes which are inclined with respect to the imposed electric field.

5. Actuator (14) in accordance with claim 1, wherein the particles constituting the conducting means (18) have a size of 0,1 μm– 5 mm, preferable 10 —μm to 500 — μm, measured in parallel to the externally imposed electric field.
~~beskrive ved d_char?~~

6. Actuator (14) in accordance with claim 1, wherein the angle — λ between the sloping planes and the microchannel walls (20b) is 0 – 80 degrees.

7. Actuator (14) in accordance with claim 6, wherein the angle — λ between the sloping planes and the microchannel walls (20b) is 30 – 60 degrees

8. Actuator (14) in accordance with claim 1, wherein the space between the different conducting means (18), and between the conducting means (18) and the channel walls (20b) is between 0 and $2a_{char}$, preferably between 1/8 and ½ a_{char}.

9. Actuator (14) in accordance with claim 1, wherein the conducting means (18) contains several layers of conducting particles, both axially and longitudinally in relation to the flow direction.

10. Actuator (14) in accordance with claim 1, wherein the conducting means (18) consist of a ionic or electronic or hole conducting material.

11. Actuator (14) in accordance with claim 1, wherein the conducting means (18) has a conductivity of at least 5 times the conductivity of said fluid, or preferable of at lest 10 times the conductivity of said fluid.

12. Actuator (14) in accordance with claim 1, wherein the electrical connection means (16) contains a pair of electrodes arranged upstream or downstream with respect to the microchannel segment (20a).

13. Actuator (14) in accordance with claim 1, wherein the electrical connection means (16) is adapted to provide an electrical field (E) parallel to the direction of the transported fluid.

14. Actuator (14) in accordance with claim 1, wherein the electrical connection means (16) applies an alternating field.

indirect actuation, e.g. setting the membrane of a peristaltic pump in motion by directly actuating a chosen liquid in contact with one side of the membrane, while the other side is in contact with the fluid of primary interest.

Smooth surface: By this should be understood that surface irregularities should be less than 5% of d_{char}, preferably less than 1% of d_{char}.

Characteristic diameter d_{char}: The dimension of the conducting means measured in parallel to the direction of the externally imposed electric field. When a number of conducting particles are contacting each other in the direction of the electric field, d_{char} is taken to be the whole length of the resulting conducting structure, measured in the same said direction.

Characteristic radii a_{char}: 0.5 times d_{char}.

Substrate: The material into which the microchannel or system of channels is produced, including e.g. the silicon wafer into which channels are etched, as well as top – plate constituting the channel roof.

The micropump according to the present invention is designed to transport liquid in the area of a few nanoliter per min. to up to 50 ml per min. The amount of liquid depends on the specific applications, and is typically from several nanoliters (nl) / min for drug delivery, microliters (µl) / min for lab – on – a – chip applications , and several milliliters (ml) / min for cooling applications. For simplicity, the terms micropumps and microchannels will be used throughout the text, even if the prefix "nano" could be used for the lower part of the size range.

Figure 1 is a general outline of a microfluidic system 10 according to the invention. Preferable, the microfluidic network is arranged on or in a substrate 12. The figure shows two microchannels 20. The arrows indicate the fluid flow direction. The segment 20a is indicated as a portion of the microchannel 20. The electrical connection means (16)

establishes an electrical field E in the segment 20a and the conducting means 18 ensures that the liquid is forced in a given direction. Contacts for the electrodes 16 and sensor 22 are indicated with the reference numerical 24. It should be mentioned that the electrodes 16 could be placed anywhere in the microfluidic system, and also outside the systems, e.g. at the channel inlet and outlet. However, the designs with larger distance between electrodes are less prefered. Also, the actuator could be produced e.g. in a capillary instead of being microfabricated onto some substrate.

Figure 2 shows a top view of an embodiment of the present invention, with circular or spherical conducting means 18, which is fixed to the bottom and top of the channel section 20a. Here, the channel cross – section is rectangular. The distance between particles and between particles and the wall is approximately equal to a_{char}, thus both mixing and directed transport will take place. Also indicated on the figure are the walls of the channel 20, and position of electrodes 16 (dotted line). The flow direction is indicated by arrows.

In figure 3 is shown an embodiment of the invention with conducting means 18 shaped as two inclined (sloping) planes which are fixed to the channel walls and filling the depth of the channel (with rectangular cross section). Also shown on the figure are walls of the channel 20, position of electrodes 16 and flow direction (indicated by straight arrows). The distance between the conducting means 20 is varying from approx 2 – 0.5 a_{char}, thus some mixing will be obtained in addition to directed transport.

Figure 4 shows an embodiment similar to that shown in figure 3, but with conducting means 20 shaped as semicircular cylinders or semispheres. The distance between the conducting means 18 is approximately one characteristic diameter $2a_{char}$, leading to both mixing and directed transport. The positions of electrodes 16 are indicated by dotted lines.

Figure 5 shows a microactuator with two connected layers of conducting means 18 shaped as circular cylinders or spheres in the flow direction. The conducting means are

fixed to the bottom and top of the microchannel 20. The position of electrodes 16 is indicated (dotted line), as well as the direction of flow. As the distance between the conducting means 18 and channel wall is approximately equalling a_{char}, both mixing and pumping will be obtained.

Figure 6 shows a sideview of a microchannel 20 including actuator segment 20a, substrate 12 (e.g. silicon, glass or polymer) and electrodes 16. Also shown is the channel top – plate (chosen among the same materials as the substrate), and flow direction. The segment of conducting means is indicated by dotted lines, but the conducting means 18 is not shown.

Figure 7 shows a top – view of the same structure as shown in figure 6.

Figure 8 shows an embodiment of the invention with substrate 12, and ellipsoidal or elliptical cylindrical conducting means 18, which is fixed to the channel bottom and top. Possible positions for electrodes 16 are indicated by dotted lines. As the distance between conducting means 18 is small, mostly directed pumping will be obtained.

The actuator in figure 9 is similar to the one depicted in figure 8, but has two layers of conducting means 18 in the flow direction, which are not in contact with each other.

Figure 10 shows a microactuator with two inclined (sloping) conducting means 18, which is fixed to the channel walls and filling the whole channel dept. The distance between the conducting means 18 is relatively small compared to a_{char}, thus directed transport will be obtained. Possible electrode positions are indicated by dotted lines.

Figure 11 shows another embodiment with sloping conducting means 18 similar to that shown in figure 10, but with additional layers of conducting means in the channel width.

Figure 12 shows a microchannel 20 with a widened channel segment including the channel segment 20a (limited by two dotted lines) containing the conducting means 18.

The latter is not shown on the figure. This actuator has the advantage of building up larger pressures.

In figure 13 is shown part of the channel 20 including microactuator section 20a, where the conducting means 18 is part of the channel walls. Circular shaped electrodes 16 is also shown. As the distance between the conducting means is small compared to a_{char}, significant directed transport will be obtained. Because of the higher conductivities of the conducting wall sections 18 compared to the liquid, the local electric field deviates towards said conducting means 18, creating both normal and tangential field components.

In figure 14 the geometry of part of the microchannel section 20 including microactuator section 20a and with sloping conducting means 18 is displayed. The angle between channel wall and surface of conducting means λ is indicated, as well as original channel diameter d_0, normal distance between original channel wall and a point on the inclined plane h, characteristic diameter d_{char}, and channel length axis x.

Figure 15 shows the microchannel section 20a with conducting means in an embodiment with sloping conducting means 18 of circular geometry concentric to the rest of the microchannel 20.

In figure 16 is shown a microchannel with four electrodes. Here, the conducting means 18 constitutes part of the (cylindrical) channel, while the electrodes 16 placed up and downstream to this section (not shown). The conducting means could be a tubular ion – exchange membrane. A second pair of electrodes 16b induces the electric field normal to the flow, responsible for the SCR build – up. One of these are shaped as a circular tube concentric to the microchannel 20, and with a larger radii. It could consist of metal foil or -deposit, some conducting coating or surface treatment or other. The other electrode inducing the normal field could be a metal wire, which should be kept at some distance from the conducting means 18 by means of pieces of isolation or other fixing method. Preferably, it should be placed along the channel center axis.

Figure 17 shows a top view of the microchannel section 20a containing the conducting means in which one conducting particle is placed in a widening of the channel 20, keeping the area in a distance up to approximately $2a_{char}$, open for flow, resulting in efficient mixing. The next part of the microchannel section 20a mainly gives directed pumping, as the distance between conducting means and wall is below 0.5 a_{char}.

In figure 18 is displayed a channel cross section in an experimental setup, where conducting means 18 are fixed between two plates with microfabricated semicircular holes. The microchannel length direction is directed normally to the paper plane, and the channel side – walls are produced by sealing the plates by a sealing mass on each side. Spherical sulphonated styrene – divinylbenzene ion – exchange particles were used as conducting means 18.

Figure 19 shows a top view of a microfabricated hole plate used for the experimental setup in figure 18.

Figure 20 shows a top view of the experimental setup, including conducting means 19, electrodes 16 and two liquid reservoirs on each side of the microchannel 20.

Generally, the conducting means 18 could have shape of ellipsoids, circular or elliptical cylinders, of spheres, semispheres, or any shape with a circular cross section. Further, it could have the shape of planes having an angle between 0 – 85 degrees with the applied electric field, preferably with an angle within 30 – 60 degrees. The conducting means should have a conductivity of at least 5 times that of the liquid to be actuated, preferably at least 10 times this conductivity.

The characteristic dimension of the conducting means (18) d_{char} should be within 0.1 μm and 5mm, but for most applications between 10 μm and 500 μm.

For applications where predominantly directed EO2 pumping is desired, the space between the conducting particles 18, and between the conducting particles 18 and the

channel walls 20a, should be between 1/8 and ½ a_{char}. The distance to the wall does not apply where the conducting means 18 is attached to the walls, as in figure 3, 4 and 10, 11. For one layer of particles in the flow direction, this distance could be smaller or zero. If there is more than one layer, there must be space between the particles in each layer, or between the particles in adjacent layers, or both.

If mixing should also be obtained, the distances could be up to 2 a_{char}. For the largest distances, mixing is predominantly obtained.

Figure 13 shows an embodiment where the conducting means 18 is part of the microchannel wall 20. This is a special aspect of the invention and the EO2 condition is established by a declining in the local electrical field near the conducting means 18.

The length of the conducting areas should be the same as for conducting particles. The channel geometry could be rectangular, circular or elliptical. Here, d_{char} is the length of the conducting field, measuring in the flow direction. By analogy to the conducting particles, the distance between two opposite conducting walls should preferably be 1/8 – ½ a_{char} for obtaining directed flow. The conducting area could cover part of the channel circumference (e.g. the walls), or the entire channel circumference.

For the structure with conducting walls depicted in figure 13, the electrodes 16 could preferably be placed at some distance from the portion 20b of the channel walls, and occupying 1/3 of the channel width or less. They could be placed closer to the electrodes 16 than described above, and they could even be placed within the area 20b of conducting walls. Also, this structure could be extended by using several rectangular blocks of conducting means in the width of the channel. In such a geometry, the ends of conducting blocks could be electrically isolated, in order to increase the tangential electric field component.

For the structures containing one pair of electrodes 16, the electrodes should be placed up- and downstream in relation to the conducting area, respectively. These could be

The underlying concept of the invention is that the tangential electric field component works on the SCR induced by the normal component. The solvated ions in the SCR are then transported similarly to the ions in the EDL for classical EO. In both cases, the bulk pore liquid is set in motion due to viscous forces.

The EO1 velocity is given by the Smoluchowsky equation,

Equation 1

$$v^{EO1} = \frac{\varepsilon\zeta E}{\eta}$$

Here, ε is the liquid permittivity, ζ the surface (zeta) potential of the wall, $E_{\parallel}$ the electric field strength parallel to the charged surface, and η the liquid viscosity. For EO2, the velocity is given by the formula

Equation 2

$$v^{EO2} = \frac{2\varepsilon a_{char} E_{\parallel} E_{\perp}}{\eta}$$

$E_{\perp}$ being the normal electric field component.

In the case of other shapes of the conducting particle, d_{char} is taken to be the dimension measured in the flow direction. The SCR charge is approximately equal to d_{char} times E.

Classical electroosmosis (EO1) is caused by transport of permanent charges (ions) in the EDL. These ions are hydrolyzed (i.e. a number of water molecules are associated to each ion) or in general solvated (other solvent than water may be used). When the electric field sets the charges in motion, water is also transported. While this effect is taking place in a

2. A (normal) potential drop which is large enough for inducing the SCR. This means that the dimensionless potential drop across one characteristic particle diameter is larger than unity, which translates into:

Equation 3

$$E > 0.013V / a_{char}$$

3. The tangential field component must not be too large, otherwise the SCR are depleted of ions, and the SCR becomes thinner. Thus, the electric potential should not exceede:

Equation 4

$$E_{max\ SCR\_flux} = \left(\frac{3}{2}\right)^{\frac{4}{5}} \frac{RT}{F} m^{-\frac{2}{5}} \kappa^{\frac{4}{5}} a_{char}^{-\frac{1}{5}}$$

Here, R is the gas constant, T the temperature, F Faraday's constant, m a dimensionless constant equaling 0.2 for aqueous solutions, and κ the inverse Debye – length.

4. The conducting media could be conducting by means of ions, electrons or holes; and it could be a conductor or semi – conductor. It should preferably be non – porous, but could also be porous, although this would lead to a reduced velocity. The best results are obtained for a permselective ion – conductor.

5. In order to avoid water splitting the concentration in the SCR should exceed the ion – product of water. As EO2 convection is counteracting the lowering of concentration resulting from polarization, a lower electric field strength above which no water splitting is present is observed:

automatically or manually changed and controlled during operation. This could be done based on information of the system performance obtained from the system microsensors.

Preferably, the signal frequency should be chosen to be higher than the inverse electrode polarization time,

Equation 7

$$t_{pol\_el} = \frac{L}{\kappa D}$$

where L is the distance between electrodes, κ is the inverse Debye length (inverse EDL thickness), and D the diffusion coefficient of current carrying ions.

If an alternating or pulse electric signal should be applied, the maximum frequency is determined by the hydrodynamic time constant,

Equation 8

$$t_{HD} = \frac{a_{char}^{2}}{\nu}$$

where ν is the kinematic viscosity of the liquid.

PRODUCTION, MATERIALS, EXAMPLE SYSTEMS

Microfluidic devices can be produced by means of micromachining and processing techniques used in the microelectronics industry. This also applies to the micropumps according to the present invention. These methods allows one to make channels as well as

CLAIMS

1. Actuator (14) for use in a microfluidic system (10), wherein said microfluidic system (10) comprises a fluid network optionally in a substrate (12) consisting of at least one microchannel (20) arranged for transporting fluids; and an electrical connection means (16) for application of an electric field (E) across a segment (20a) of said microchannel (20) such that electroosmotic flow is induced in said segment (20a), characterized in that said segment (20a) comprises conducting means (18), wherein a surface portion of said conducting means (18) is curved, or inclined with respect to the electrical field (E).

2. Actuator (14) in accordance with claim 1, wherein the conducting means (18) has the shape of ellipsoids, spheres, cylinders, elliptical cylinders or cones.

3. Actuator (14) in accordance with claim 1, wherein the conducting means (18) consist of small cylinders with the longitudinal axis normal with respect to the fluid flow direction.

4. Actuator (14) in accordance with claim 1, wherein the conducting means (18) has the shape of particles with planes which are inclined with respect to the imposed electric field.

5. Actuator (14) in accordance with claim 1, wherein the particles constituting the conducting means (18) have a size of 0,1 μm– 5 mm, preferable 10 μm to 500 μm, measured in parallel to the externally imposed electric field.

6. Actuator (14) in accordance with claim 1, wherein the angle λ between the sloping planes and the microchannel walls (20b) is 0 – 80 degrees.

7. Actuator (14) in accordance with claim 6, wherein the angle λ between the sloping planes and the microchannel walls (20b) is 30 – 60 degrees

8. Actuator (14) in accordance with claim 1, wherein the space between the different conducting means (18), and between the conducting means (18) and the channel walls (20b) is between 0 and $2a_{char}$, preferably between 1/8 and ½ a_{char}.

9. Actuator (14) in accordance with claim 1, wherein the conducting means (18) contains several layers of conducting particles, both axially and longitudinally in relation to the flow direction.

10. Actuator (14) in accordance with claim 1, wherein the conducting means (18) consist of a ionic or electronic or hole conducting material.

11. Actuator (14) in accordance with claim 1, wherein the conducting means (18) has a conductivity of at least 5 times the conductivity of said fluid, or preferable of at lest 10 times the conductivity of said fluid.

12. Actuator (14) in accordance with claim 1, wherein the electrical connection means (16) contains a pair of electrodes arranged upstream or downstream with respect to the microchannel segment (20a).

13. Actuator (14) in accordance with claim 1, wherein the electrical connection means (16) is adapted to provide an electrical field (E) parallel to the direction of the transported fluid.

14. Actuator (14) in accordance with claim 1, wherein the electrical connection means (16) applies an alternating field.